Characteristics of linear antennas immersed in an anisotropic plasma over a ground plane

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論　文　内　容　要　旨

The space shuttle program and the prospect of nucler fusion provided increased motivation for research on properties of antennas in plasmas. Antennas are well-known not only as important parts of communication systems but also as useful devices for diagnostics of the surrounding medium. These important properties of an antenna are determined by its physical shape, the properties of the surrounding medium and its feeding conditions. Again, the presence of boundaries and obstacles in the vicinity of an antenna can greatly modify the transmitted and received signals. A great variety of distortions in the signal path and signal power can occur with the intervention of these scattering and reflecting objects. When the medium is anisotropic, studies of antenna properties in the presence of these obstacles and boundaries are of interest for studying the effects of inhomogeneities which are practically encountered in the ionosphere, in thermonuclear fusion, in layers of minerals, in crystals and ferrites. The most fundamental approach to these problems can be the study of the characteristics of antennas in an anisotropic plasma over a ground plane, as has been the subject of study in this dissertation.

With a general introduction in Chapter 1, a general formulation of the vector dyadic Green's function for sources over a ground plane covered with an anisotropic plasma has been discussed in Chapter 2. Approximate solutions of the problem have been derived in Chapter 3. Radiation patterns of a monopole antenna in a uniaxially anisotropic plasma have been studied in Chapter 4. The results have been compared with dipole patterns in an unbounded uniaxially anisotropic plasma. The impedances and mutual impedances of linear antennas over a ground plane covered with an anisotropic plasma have been calculated in Chapter 5. Experimental verifications of the calculated impedance and mutual impedances of monopole antennas have been given in Chapter 6. The dissertation has been concluded with a general discussion in Chapter 7. The important findings of this study can be abstracted as below.

Starting from the radiations from sources over a ground plane covered with an anisotropic plasma, a study has been given to the characteristics of linear antennas immersed in an anisotropic plasma over a ground plane. The major points of interest are reflection mechanism at the surface of the ground plane, radiation pattern of monopole antennas, input impedances of monopole antennas and horizontal dipole antennas, and mutual impedances between monopole antennas over a ground plane. The inclination of the static field with respect to the ground plane has been kept arbitrary and the theoretical analysis of antenna characteristics is restricted to the uniaxial and quasi-static approximations of a cold magnetoplasma. Experimental investigations of the input and mutual impedances between monopole antennas in a magnetoplasma have also been carried out.

In a study of the radiations from sources over a ground plane covered with an anisotropic plasma, the vector dyadic Green's fuction has been derived satisfying the boundary condition and the radiation condition. The solution has been constructed from the plane wave spectra of the two characteristic modes, i.e. the ordinary O-mode and the extra-ordinary X-mode. The two characteristic modes are generally coupled at the surface of the ground plane so that the reflected field consists of the OO, XO, OX and XX modes of birefringent reflections. From a ray optical description using the pertinent refractive index profile it has been found that for an arbitrary inclination of the static magnetic field the reflection at the surface of the ground plane is generally nonspecular and ray crossing, focusing, lateral waves and surface waves can occur.

Due to the diverse curvatures of the wave number surfaces corresponding to the medium, the quantitative description of radiation in such medium is rather complicated. For simplicity of the analysis of antenna characteristics, the uniaxial and quasi-static approximations have been employed. Simplified expressions for the coupling coefficients have been derived using the uniaxial approximation and a concept of images for the four reflected modes has been enanciated. The four reflected modes are delivered by four images having different locations. Under hyperbolic plasma conditions there can be focusing in the vicinity of the ground plane instead of forming images.

The quasi-static solution for the near field of a small source over the ground plane has been obtained in closed form and the image location for the secondary field has been found to be displaced from the conventional location enlarging the illuminated zone of the resonance cone. This solution is particularly significant for short antennas for ionospheric probing.

Radiation pattern of a monopole antenna in a uniaxially anisotropic plasma has been computed for arbitrary inclination of the optical axis with parameters suitable to represent an elliptic plasma condition. The field expressions involving double Fourier integrals have been asymptotically evaluated by the steepest descent method and radiation pattern has been computed for Hertzian type monopole and electrically long monopole. Comparisons have been shown with dipole patterns in an unbounded uniaxially anisotropic plasma. Considerable differences can be observed between the power patterns of the two configurations. A strong beam is radiated from the monopole via O-mode for some inclinations of the optical axis and is attributed to lateral waves propagating along the ground plane and shedding energy back into the medium.

Since the knowledge of antenna impedances in a magnetoplasma is important for interpretation of the data obtained from rocket and satellite exploration of the ionosphere and other planetary environments, a thorough study has been given to the input impedances of monopole antennas over a ground plane that corresponds to the vehicle surface of the rocket. A short monopole impedance with a triangular current distribution has been obtained in a closed form and the results have been numerically studied in comparison with a dipole impedance available in the current literature. Significant differences can be observed under hyperbolic plasma conditions. An oblique resonance anomaly occurs when a surface of the resonance cone emanating from the driving point of the monopole coincides with the monopole axis. Another anomaly occurs when the resonance cone coincides with the ground plane. From study of an electrically long monopole using a sinusoidal current distribution the resonances corresponding to the antenna length have been observed. In a study of the input impedance of a short horizontal dipole over the ground plane, oblique resonance anomaly has been found to occur when the reflected cone grazes the dipole ends. The mutual impedance between two short monopoles has been calculated and it has been found that the ground oblique resonance anomalies are salient features in the mutual impedance and can be used for plasma diagnostics.

From laboratory measurement of an electrically long monopole impedance in magnetoplasma, the resonance cone and the resonances corresponding to the antenna length have been observed. The measurement of the mutual impedance between short monopoles in a magnetoplasma with an arbitrary inclination of the static magnetic field has revealed some interesting electromagnetic phenomena. The method is based on the measurement of the scattering matrix between two monopoles so that the self impedance, mutual impedance and propagation characteristics have been simultaneously explored. The ground resonance predicted theoretically has been observed in the measured data. Also the effects of focusing in the vicinity of the ground plane have been observed in the measured results. It has been pointed out for the first time how to obtain the plasma frequency, cyclotron frequency, collision frequency and the thickness of the ion-sheath from direct measurement of the scattering coefficients between two monopoles in a magnetoplasma. This method employed for the first time and the relevant calculations seems appealing for inospheric and thermonuclear measurements.

審 査 結 果 の 要 旨

宇宙開発に関連して，プラズマ中に置かれたアンテナについては多くの研究がなされているが，地磁気の影響を考慮し，かつ，反射板を使用する場合については，通常の反射法則が成立しないことに関連する問題がまだ幾つか残されている。

著者はこの点にかんがみ，地板上の異方性プラズマ中に置かれた線状アンテナについて，理論と実験の両面から研究を行ない，反射電磁界の性質を明らかにすると共に，アンテナの諸特性に対する地板の影響を種々の場合について定量的に求め，多くの新しい知見と資料を与えた。本論文は，これらの成果をまとめたもので全文7章からなる。

第1章は緒論である。

第2章では，導体板上の半無限プラズマ空間中に微小アンテナを置いた場合の，電磁界の積分表示式を求め，反射波を表わす各項の物理的意味を述べている。

第3章では，一軸異方性で近似した媒質中で前章の表示式を計算し，地板によって生ずる鏡像について検討を行なっている。その結果，通常の鏡像の他に，異方性の軸方向や観測位置などに関係する三つの点にも鏡像を考えると，電磁界の説明が簡明になるという興味ある知見を得ている。

第4章では，モノポールアンテナの放射指向性を計算し，ダイポールにした場合との差異を定量的に明らかにしている。この研究はその差異をはじめて示した点で高く評価されている。

第5章は，線状アンテナのインピーダンスの理論値について述べたものである。アンテナ長が波長に比べて短い場合，一軸異方性の場合など，種々の場合について自己および相互インピーダンスの周波数特性を求め，数多くの図表により地板の影響を明らかにしている。

第6章では，大型真空室内に磁気プラズマを発生させ，諸パラメータを変化させて行なったインピーダンスの実測結果について検討している。プラズマ空間の大きさが有限であることを考慮すると，理論値との一致はかなり良いことが示されている。

第7章は結論である。

以上要するに，本論文は地板上の異方性プラズマ中に置かれたアンテナについて，通常の反射法則が成立しないことに関連する諸問題を理論と実験の両面から研究し，アンテナの諸特性に対する地板の影響についての多くの新しい知見と資料を与えたもので，通信工学上寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。